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Hydro-geophysical Investigation Using Seismic Refraction Tomography to Study the Groundwater Potential of Ahmadu Bello University Main Campus, within the Basement Complex of Northern Nigeria

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Abstract
The investigation was carried out at the built up area of Ahmadu Bello University, main campus samara, Zaria. In order to map the ground water potential structure of the area a seismic refraction tomography method was used. The compressional seismic wave (P-wave) velocity variations provided information about the rock distribution in the subsurface. A close interpretation of the seismic refraction tomography model shows a reliable image of the velocity layers from which the saturated layers are delineated. Six profiles of 5 m geophone spacing were carried randomly around the study area. The results obtained from each of the profile highlighted the presence of structure(s) that can support underground water and hence the ground water potential can be determined.
Keywords: Tomography, lithology, velocity layer, seismic wave, staking.

1. Introduction

In many developed and developing countries there is not only a heavy reliance on round water as a primary drinking supply but also as a supply for both agriculture and industrial use. The reliance on groundwater is such that it is necessary to ensure that there are significant quantities of water and that the water is of a high quality. The use of geophysics for both groundwater resource mapping and for water quality evaluations has increased dramatically over the years in large part due to the rapid advances in microprocessors and associated numerical modelling solutions (Leucci, G., et al 2007).

Seismic tomography signifies a revolution in earth sciences. It has had far-reaching and deep impacts on the geological and the geophysical community and will continue to influence the future developments in earth sciences. A seismic tomography image has been particularly useful in understanding the earth's structure and its geological events.

Seismic refraction methods have several applications ranging from oil exploration to mineral and water exploration. Mota (1954), Haeni (1988), have highlighted the major use of seismic refraction to map the depth and geometry of the subsurface, where water tables can be identified. Young et al (1998) used high resolution seismic refraction technique to define the structural control and the base of alluvium aquifers on the Batinah plain in the Gulf of Oman. Ugwu & Nwankwoala (2008) have also used this technique to identify water bearing sand where water can be found. A combination of seismic refraction techniques with others, have also helped in identifying water bearing layers like, Wach et al (1979), Alhassan et al (2010), Jegede et al (2011), Abdullahi et al (2011) and Sayed et al (2012).

This research work aims at determining the water bearing layers (aquifer) of Ahmadu Bello University main campus. The objective will include; determination of the thickness of the weathered layer, depth to the basement, possible fractured zones and subsurface lithology.

2. Location and Geology of the Study Area

The study sites Ahmadu Bello University main campus in Zaria, which is about 15.5km from the well-known Zaria City, is approximately bounded by longitude $7^0 38^1$E and $7^0 39^1$E and latitude $11^0 09^1$N and $11^0 10^1$N as shown in Figure 1. Ahmadu Bello University is a part of the gently undulating peneplain that extends from Lake Chad to Sokoto and Northward from Southern Kaduna into the Republic of Niger. Zaria is underlain by Precambrian rocks typical of Nigeria basement complex, which bear the imprint of thermo tectonic event dating from Achaean to early Paleozoic times (McCurry, 1970). The study site, shown in Figure 1, is underlain by Precambrian rocks of the basement complex with muscovite biotite-gneiss in the south-western part of the campus while the north-eastern part is underlain by biotite granite-gneiss (Eigbefo, 1978).

Generally, the entire area is underlain in part by Pre-Cambrian rocks which lie in the mobile zone between the West African and Congo cratons. These Pre-Cambrian rocks consist of migmatites, gneisses and north-south trending metasedimentary rocks, intruded by a series of granitic and mafic-ultra-mafic rocks of late Pre-

Cambrian to early Palaeozoic age as McCurry (1973) reports.

3. Principles and Theory of Seismic Methods

A seismic wave is acoustic energy transmitted by vibration of rock particles under the earth. They are short-lived parcels of elastic strain energy known as pulses that propagate from a source point through the earth and containing a wide range of frequency. The propagation of seismic (energy) disturbance through a heterogeneous medium is extremely complex although it can be expressed in some equation, where the velocity, travel time, distance can be used to predict the elastic properties of the region through which they pass through (Leucci, G., et al 2007).

4. Methodology

4.1. Seismic refraction tomography

In the seismic refraction method, the seismic waves, created by artificial sources such as a hammer, propagate through the medium and are refracted at interfaces, where the seismic velocity or density changes. Seismic refraction tomography is an imaging technique that generates a cross-sectional picture image of a medium by utilizing the medium's response to the nondestructive, probing energy of an external source. In this research work a 24-channel seismograph (Abem Terraloc Mk6) was used with a sledge hammer striking a rubber plate as an energy source and a shot-point at each geophone position. Data were stacked at least three times for each shot. Six profiles (as shown in Figure 2) of 120m profile length at geophone intervals of 5m were taken around the campus. The software ReflexW 3.0 version, developed by Sandmeier (2002), was used to perform the data processing and to interpret the seismic refraction tomography data. The data collected from the filed was subjected to different stages of processing to enhance the signal-to-noise ratio. The was first filtered by applying a bandpass filter (with an upper and lower frequency of 150Hz and 50Hz respectively) to improve the quality of the real signal. The next step is to pick the first arrival seismic wave to the receiver. First-arrival travel times picked manually (Figure 3) and ray paths are calculated by the ray tracing method based on Huygen's principle (Parasnis, et al, 1997). This arrival time picks are used to plot the travel time curves from where the velocity layers can be estimated from the reciprocal of the slopes obtain in the plot.

An initial velocity model is estimated. In this case, a two velocity layer model is represented by the results obtained from the simple interpretation of the travel time plot from the seismic refraction data. Refraction rays are traced through this model to calculate the depth (d) to reflectors by using the following formula;

$$d = \frac{1}{2} x_{cr} \sqrt{\frac{v_2 - v_1}{v_2 + v_1}} \qquad (1)$$

$$d = \frac{1}{2} t_i \frac{v_2 v_1}{\sqrt{v_2^{\,2} - v_1^{\,2}}} \qquad (2)$$

Where v_1 is the velocity of the first layer, v_2 is the velocity of the second layer, x_{cr} and t_i are the critical distance and intercept time from the velocity travel time graph.

The parameters calculated from the travel time plot of the first arrival are inputted in the software by inversion to generate the seismic tomography model after iterations. The iterations are stopped when the root mean square travel time residual (difference between the calculated travel times for the initial model and the observed ones) is less than the average travel time pick error (Parasnis, et al, 1997).

5. Interpretation of the tomography section

For groundwater resource mapping it is not the groundwater itself that is the target of the interest rather it is the geological situation in which the water exists. The results of the inversion of the seismic data (tomography section) shown in figures 4, 5, 6, 7, 8 and 9 are the variation of the seismic waves in the subsurface of the earth. The tomography section is the colour representation of image of the earth's structure, with each colour (characterized by the rainbow colours of blue, green, yellow, orange, red, indigo to purple/violet colours) representing a iso-velocity layer. Each Tomography section has a legend colour bar code of velocity range and each of this colour represent a velocity layer. The distortions at the beginning and at the end of each model are as a result of the edge effect created by the software due to the shadow zone (window) when collecting the data in the field.

Each seismic refraction tomography models can be divided into three main layers of overburden, weathered and fresh basement based on; the velocity classifications from standard values (Table 1), the geologic information of the region and the borehole log obtained around the study region. With this information, the tomography of the study area can be explained as follow.

The first layer in blue colour (between 0 and 10 m in depth), where the lowest seismic velocities (ranging from about 600 m/s to about 1000 m/s) were detected, corresponds to an area within the top soil (overburden) which is mainly laterite and sandy clay (Figures 4, 5, 6, 7, 8 and 9). These velocity values are typical of most overburden subsoil in the region.

The second layer made up of the green, yellow and red colours (between 10m to 20m or 25m deeper in some), is characterized by a higher seismic velocities (ranging from about 1000 m/s to about 2500 m/s). The area is mainly sandy clay, clay and saturated soil of fine to medium and coarse grain size. This is the weathered basement as indicated in Figures 4, 5, 6, 7, 8 and 9.

The third layer which is violet (purple) in colour shows an increase of seismic wave velocity (from 2600m/s and above), could be due to more compact soil of probably quartz occurring with gneiss as fresh crystalline rocks. Figures 4, 5, 6, 7, 8 and 9.

Removing the edge effects, figures 5, 7, 8 and 9 shows weathering extending far into the fresh basement. With the thickness of the weathered basement, this region shows to have very good potential for underground water. Figure 5; have showed also an indication of a fractured zone (between 60m to 90m along the profile length) that extended far into the fresh basement. Figure 5, 7, 8 and 9 also shows an undulating topography of the weathered basement. A syncline nature of the basement is also a good reservoir for water hence the potential zone for water. However, figure 4 and 6, show a shallow depth to fresh basement, with very thin weathered layer (compared with other profiles) which may not be good enough to support water, hence a poor potential site for underground water. Table 2 shows the summary of results from each profile, with an indication of the potential of the region.

6. Conclusion

The results obtained from each of the profile around the campus have highlighted the presence of structure that can support underground water and hence the ground water potential is very high. Of the six profiles, four has very good structures (which consist of the thickness of the weathered layer, the lithology, and the syncline nature of the basement) for good yield of ground water. Figure 5, which is shows a fractured basement has one of the best site for a large yield of underground water. The general depth to the weathered basement is about 10m and to the fresh basement is about 25m, this gives an estimate of the required depth to be drilled. The ground water potential in the study region is very promising as illustrated by the 2-dimensional seismic refraction tomography model. It is clear that with seismic refraction tomography, ground water potential zones can be easily identified and this is cost effective to drilling without appropriate geophysical investigation.

Reference

Abdullahi, A.K., Osazuwa, I.B and Sule, P.O., (2011), Application of Intergrated Geophysical Technique in the investigation of groundwater contamination: A case study of municipal solid waste leachate. Ozean Journal of Applied Sciences, vol. 4 no. 1.

Adetola, S. O. (1999). A detailed study of Teleseismic P-wave travel-time residuals at Ahmadu Bello University, Zaria. Unpublished M.Sc. Thesis, Department of Physics, A.B.U., Zaria.

Alhassan, D.U., Dangana, L.M., Salako, K.A., Jonah, S.A. and Ofor, N.P., (2010). Seismic refraction investigation of the subsurface structure at the southern part of Niger State college of Education, Minna, Nigeria. Bayero Journal of Pure and Applied Sciences, vol. 3, no. 2, p 56 – 61.

Dobrin, M. B. (1976). Introduction to Geophysical Prospecting (3rd Edition), Mcgraw-Hill, New York, 630-670.

Eigbefo, C. (1978). Hydrology of the Kubanni Drainage Basin, Zaria. Unpublished M.Sc. thesis, Department of Physics, Ahmadu Bello University, Zaria.

Gregory A., (2002) Application of Tomography, Brookfield Press, Brisbane, Australia, 476-479.

Haeni, F.P., Application of Seismic refraction technique to hydrologic studies. Book 2, chapter D2, Techniques of water resources investigations of the United States Geological Survey. TW1-D2.

Haeni, F.P., (1986). Application of seismic refraction methods inground water modeling studies in New England, Geophysics, vol. 51, no. 2, p 236 – 249.

Hayashi, K., Takahashi, T., (2001). High resolution seismic refraction method using surface and borehole data for site characterization of rocks, International Journal of Rock Mechanics and Mining Sciences: 38, 807-813.

Hydro Skill Ltd, (2006). Hydrological log of boreholes at students hostels, Ahmadu Bello University, Zaria.

Jegede, S.I., Iserhien-Emekeme, R.E., Iyoha, A. and Amadasun, C.V.O., (2013), Near-Surface investigation of groundwater contamination in the regolith aquifer of Palladan, Zaria using borhiole log and Tomogarphy techniques. Research Journal of Applied science, Engineering and Technology. Vol. 6 no. 4, p 537 – 544.

Kearey P., Hill I. and Brooks M. (2002). An Introduction To Geophysical Exploration (Ed). Tj International Ltd., Padstow, Cornwall, United Kingdom, 21-122.

Leucci, G., Greco, F., DeGiorgi, L., and Mauceri, R. (2007). Three-Dimensional image of seismic refraction tomography and electrical resistivity tomography survey in the castle of Occhiola' (Sicily, Italy). Journal of Archeaological Science 34, 233-42.

McCurry, P., (1971). Plate tectonics and the Pan African orogeny in Nigeria. Nature, 229,154 – 155.

Mota, L., (1954). Determination of dips and depths of geological layers by the seismic refraction method. Geophysics, vol 9, p 242 – 254.

Nemeth, T., Normark, E., Qin, F., (1997). Dynamic smoothing in cross-well traveltime tomography, Geophysics 62, 168-176.

Osumeje, J. O. (2008). Correlation of Seismic Refraction Tomography with geologic borehole logs in some student hostels at Ahmadu Bello University, Zaria, main campus. Unpublished M.Sc. Thesis, Department of Physics, Ahmadu Bello University, Zaria.

Parasnis, D.S., (1997). Principles of Applied Geophysics, fifth ed., Chapman and Hall, London.

Sandmeier, K.J.,(2002). Reflexw 3.0 Manual, Sandmeier Software, Zipser Strabe 1, Karlsruhe, Germany.

Sayed, S.R.M., Elkhedr, H.I., Eslam, E., Mohamed, M. and Naser, A. (2012). Seismic refraction and Resistivity imaging for assessment of groundwater seepage under a Dam site, Southwest of Saudi Arabia. International Journal of the Physical Sciences, vol. 7, no. 48, p 6230 – 6239.

Telford W. M. Geldart, L. P. and Sherriff, R. E (1990). Applied Geophysics 2nd Edition, Cambridge University Press.

Tien-when L. and Philip L., (1994), Fundamentals of Seismic Tomography, Society of Exploration Geophysicists.

Ugwu, S.A. and Nwankwoala, H.O., (2008). Application of seismic refraction method in groundwater studies in Calabar Southwestern Nigeria. Scientia Africana, vol. 7, no. 2, p 73 – 80.

Wachs, Daniel, Arad, Arnom and Olshina, (1979). Locating groundwater in the Santa Catherina area using geophysical methods. Ground Water, vol. 8, no. 6, p 8 – 13.

Young, M.E., De Bruijn, R.G.M. and Al-Ismaily, A.S., (1998). Exploration of an Alluvial aquifer in Oman by time-domain electromagnetic sounding. Hydrogeology Journal, vol. 6, p 383 – 393.

Zhao D. and Kayal J. R. (2000), Impact of Seismic Tomography on earth sciences, Department of Earth Sciences, Ehime University, Matsuyama 790, Japan.

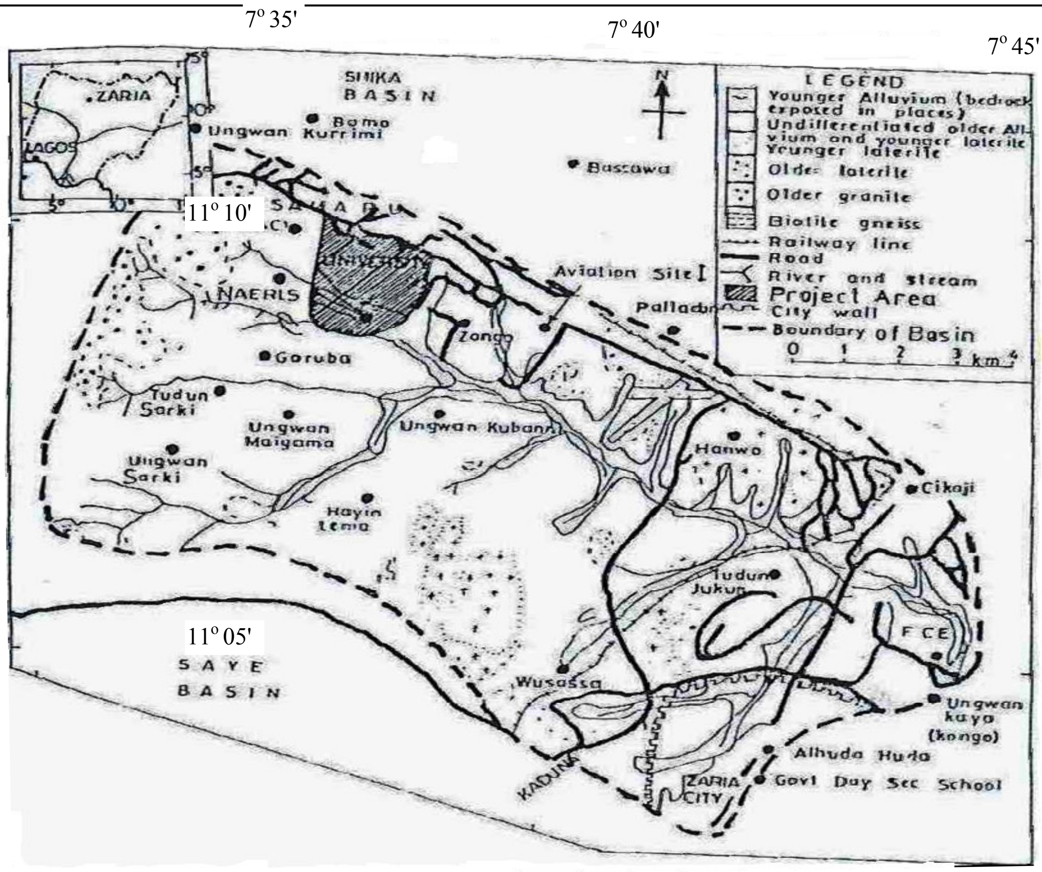

Figure 1: Geology map of the study Area (After Eigbefo, 1978)

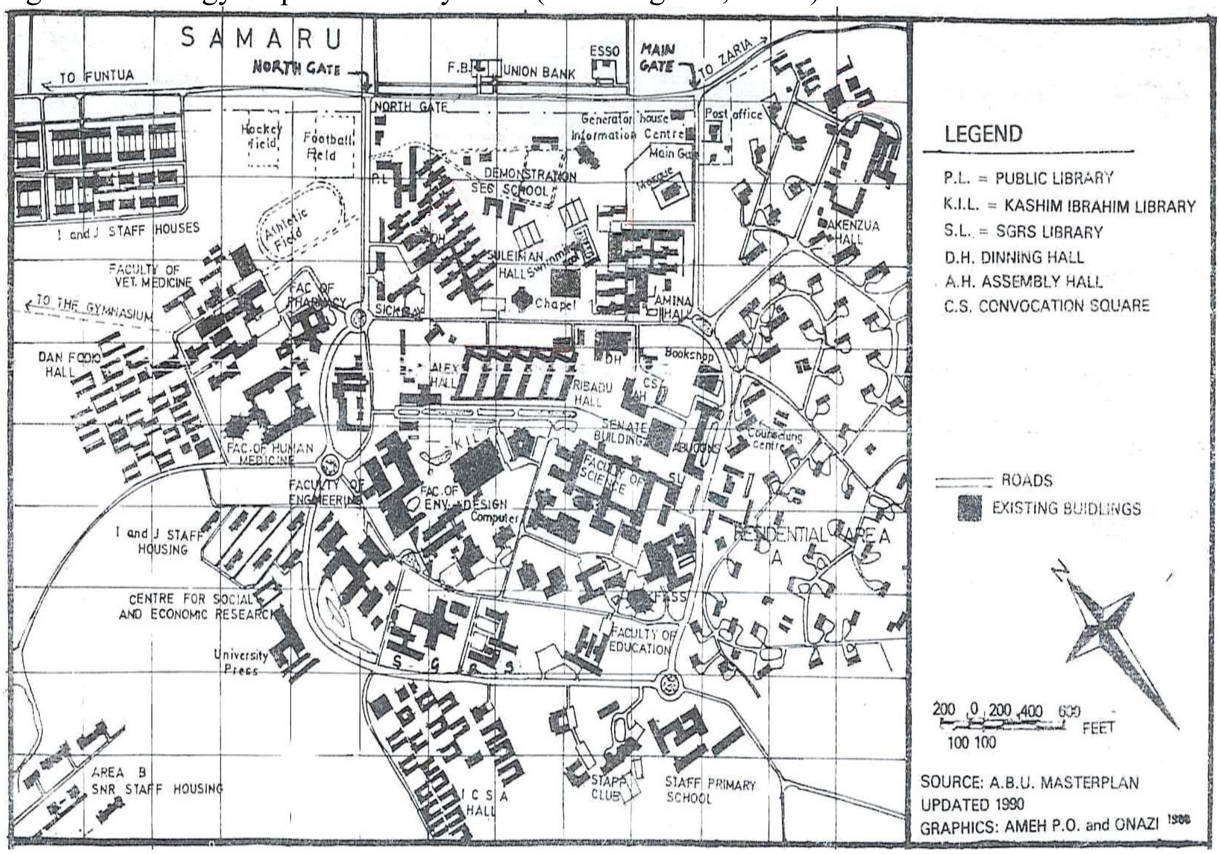

Figure 2: Map of the study area

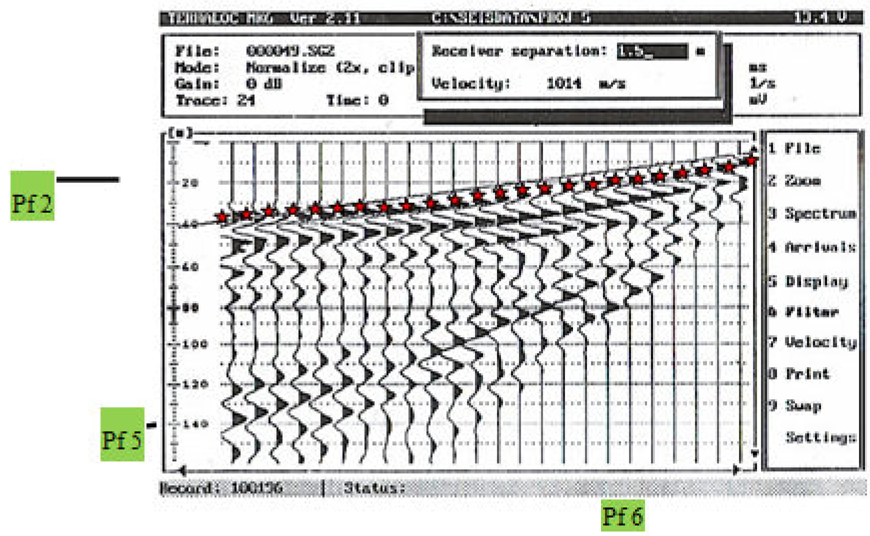

Figure 3: A single one end shot trace of the 24 geophones showing points of first arrival

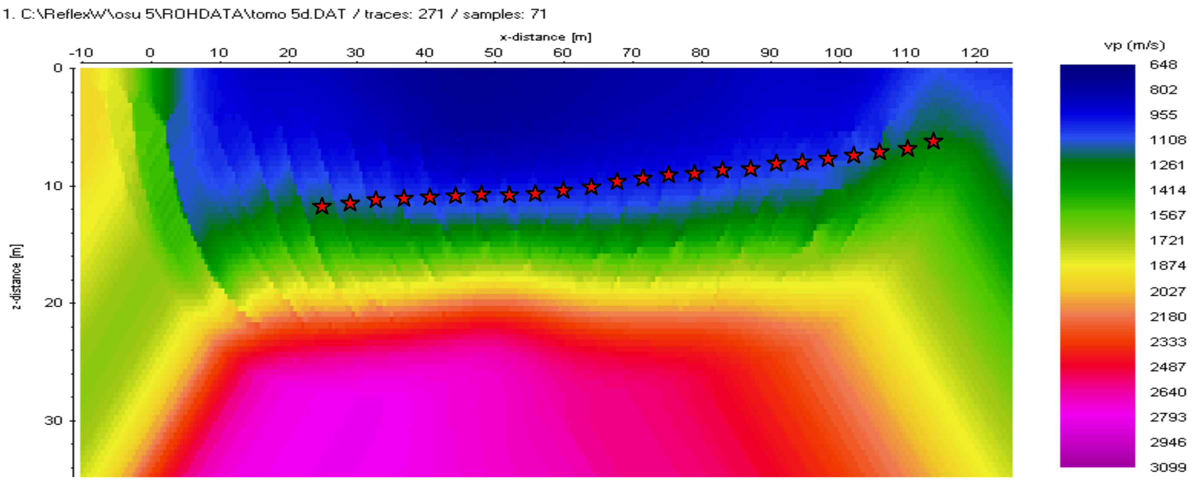

Figure 4: Tomographic Section of profile 1

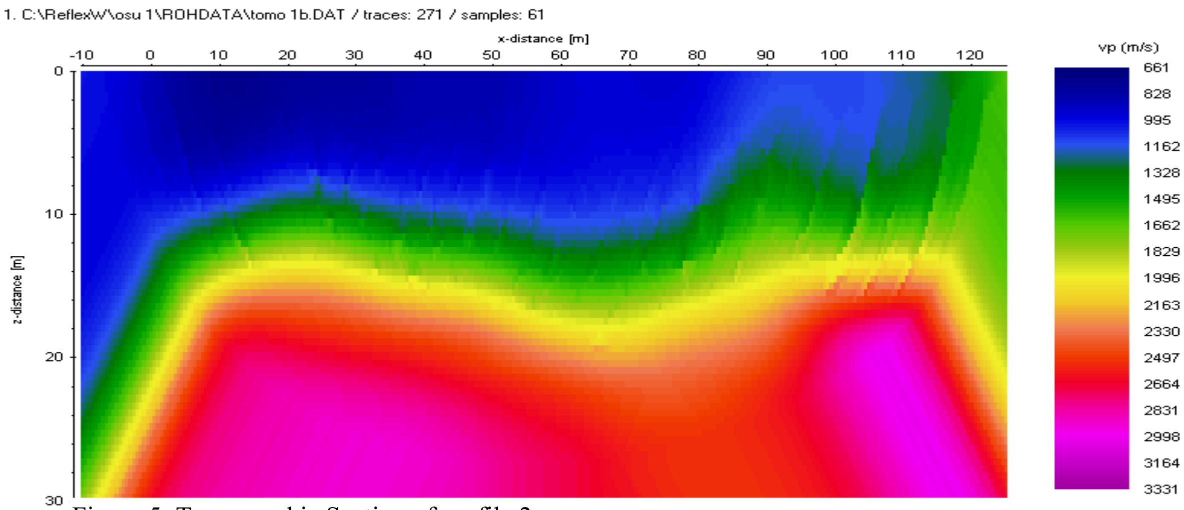

Figure 5: Tomographic Section of profile 2

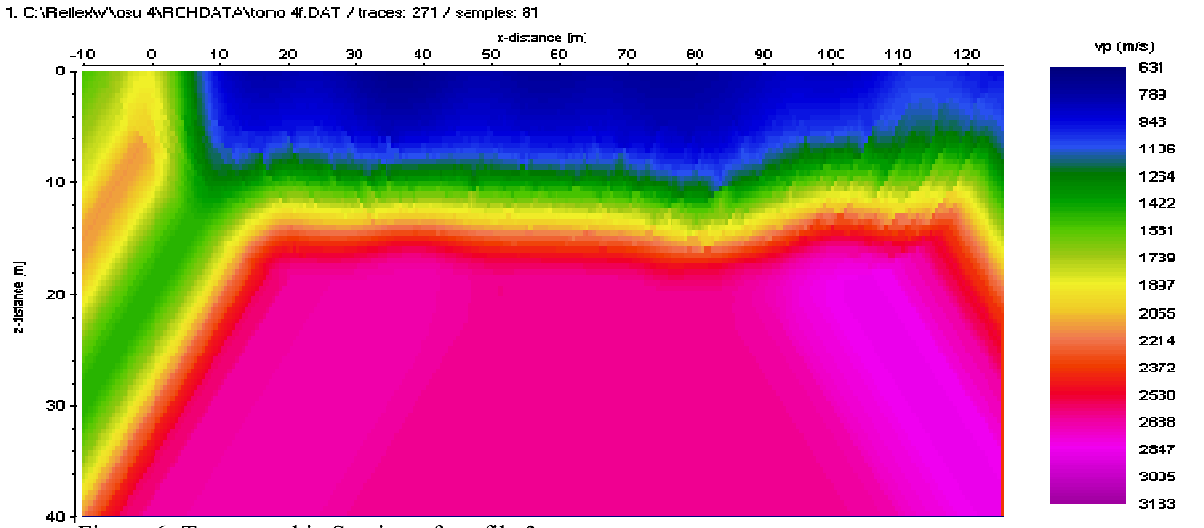

Figure 6: Tomographic Section of profile 3

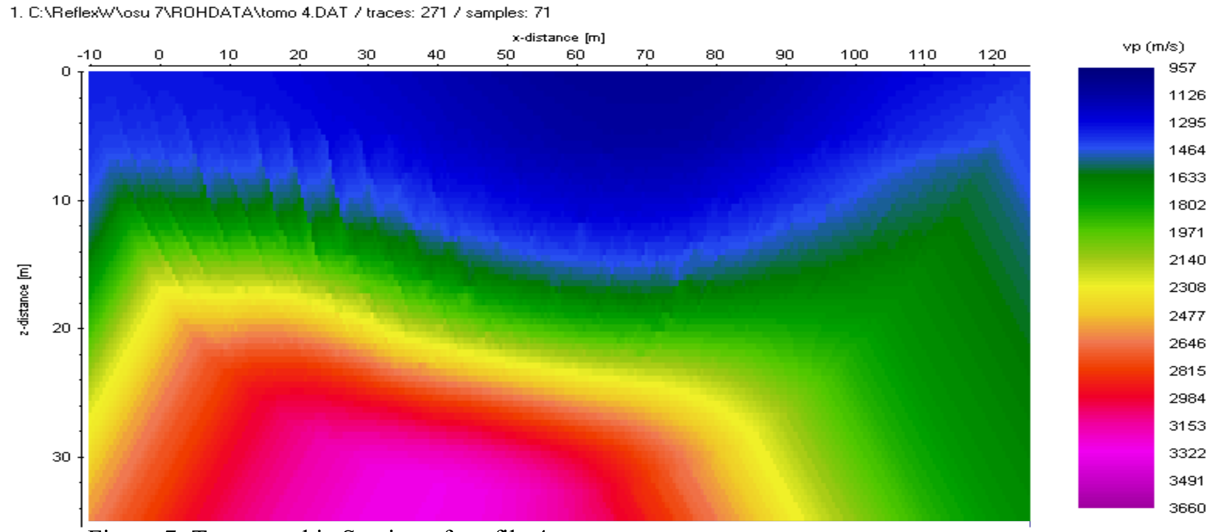

Figure 7: Tomographic Section of profile 4

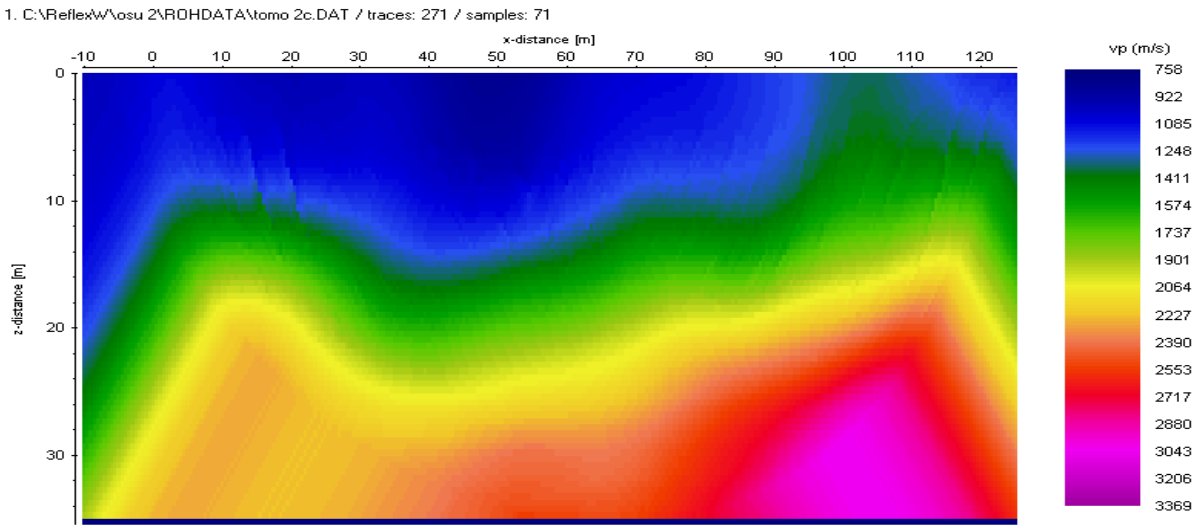

Figure 8: Tomographic Section of profile 5

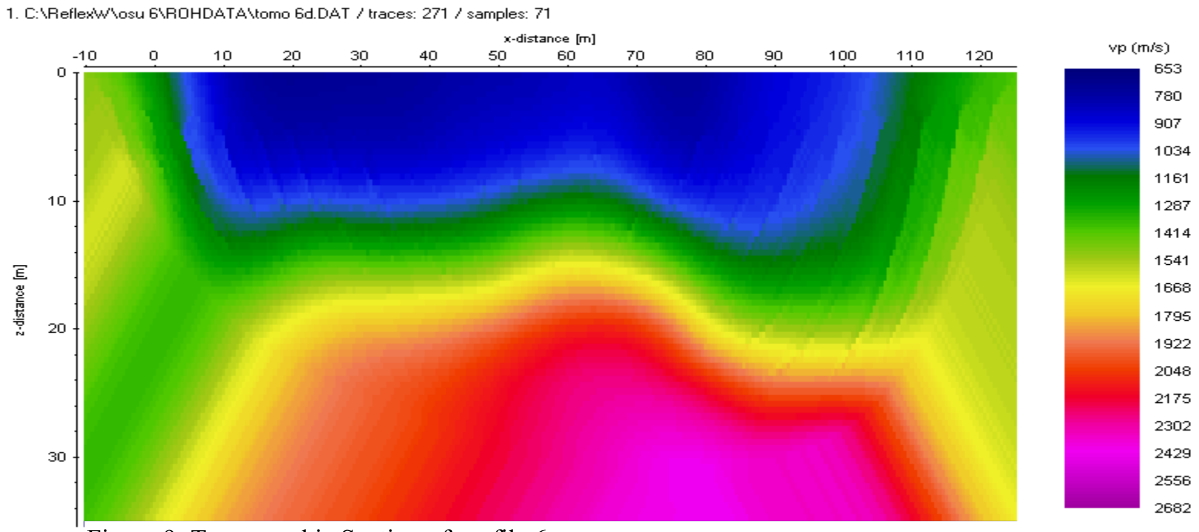

Figure 9: Tomographic Section of profile 6

Table 1: Compressional wave velocity in earth materials (Kearey, 2002)
Table 1: compressional wave velocities of earth materials.

Earth material (Unconsolidated material)	**Compressional (P-wave) Velocity m/s**
Sand (dry)	200 – 1000
Sand (water saturated)	1500 – 2000
Clay	1000 – 2500
Gneisses and Schist	2800 – 5500

Table 2: Summary of data from each tomography model.

Profiles of 120m	**Average Layer velocity**			**Weathered basement thickness (m)**	**Depth to fresh basement (m)**	**Water potential**
	Overburden (m/s)	**Weathered (m/s)**	**Fresh basement (m/s)**			
Profile 1	878	2087	2946	10.0	22.0	Fair
Profile 2	879	2737	3164	14.0	24.0	Good
Profile 3	930	2977	3005	8.0	18.0	Poor
Profile 4	1049	2666	3491	18.0	30.0	Good
Profile 5	935	2219	3206	22.0	30.0	Good
Profile 6	784	2337	2556	14.0	30.0	Good